Motor performance and motor learning as a function of age and fitness

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Abstract:

Past studies have shown that electroencephalographic alpha activity increases as people learn to perform a novel motor task. Additionally, it has been suggested that motor performance and learning decline as people age beyond 60 years, and it has been hypothesized that physical fitness may attenuate this decline through its impact on the cerebral environment. This study was designed to replicate past research by assessing changes in alpha activity as a function of learning and to extend past research by examining differences in motor performance, motor learning, and alpha activity as a function of age and fitness. VO_2max was assessed in 41 older (ages 60–80 years) and 42 younger (ages 20–30 years) participants. Participants were randomly assigned to experimental or control conditions, which differed in the amount of practice received. Participants performed trials on the mirror star trace on both an acquisition and a retention day. Results indicated that younger participants performed better and had greater learning than older participants. Fitness was not found to impact either performance or learning. Participants in the experimental group improved more than those in the control group and maintained this difference at retention, which suggests that learning occurred. Associated with these improvements in performance capabilities was an increase in alpha power.

Keywords: spectral alpha | electroencephalograph

Article:

Past research has established changes in brain activity which occur as a person learns to perform a novel task (Etnier, Whitwer, Landers, Petruzzello, & Salazar, 1996; Gliner, Mihevic, & Horvath, 1983; Grafton et al., 1992; Haier, Siegel, & MacLachlan, 1992; Landers, Han, Salazar, Petruzzello, & Kubitz, 1994). In particular, research has shown that alpha activity increases as a function of repeated practice on a task (Etnier et al., 1996; Gliner et al., 1983; Landers et al., 1994) and remains elevated at retention trials (Etnier et al., 1996; Landers et al., 1994). The alpha wave is a rhythmic wave of electrical brain activity which occurs at a rate of 8-13 Hz. The presence of the alpha wave in the electroencephalographic (EEG) recording is typically associated with quiet rest and is indicative of increases in the synchronization of neurons firing in the brain (Andreassi, 1980). Thus, the increase in alpha power which occurs with learning has been interpreted as suggesting an increase in the efficiency of the brain's activities after a person has learned a task (Haier et al., 1992). However, the conclusions which can be drawn from the studies by Gliner et al. (1983) and Landers et al. (1994) are limited because of shortcomings in their design. Most notably, neither of these studies incorporated a control group to ensure that the increases in alpha activity were due to the independent variable itself and not merely a function of becoming accustomed to the laboratory and the EEG testing procedures. However, Etnier et al. (1996) did incorporate a control group and additionally used an adequate retention interval to ensure that changes in performance capability were relatively permanent. Thus, the findings for the college-age participants (*M* age = 23.84 years) in their study provide stronger support for the conclusion that increases in alpha activity are associated with learning.

The present study was designed to replicate the findings of Etnier et al. (1996), that is, to assess EEG activity during repeated practice and retention trials of a novel motor task. Additionally, this study was intended to extend the conclusions of past research by incorporating two additional independent variables which might influence the relationship between learning and alpha activity.

One independent variable included was age. It is important to examine the influence of age on cognitive functioning and learning for two reasons. First, the population of aged adults in the United States is increasing rapidly. In 1993, the National Institute of Mental Health in conjunction with the Science Directorate of the American Psychological Association, published the Human Capital Initiative Document, which identified six critical areas for future research in the U. S. One critical area is titled "Vitality for Life: Psychological Research for Productive Aging." By the year 2025, it has been estimated that the percentage of the population over the age of 65 years will have grown from 12 to 20% (Science Directorate, 1993). Therefore, research examining the ways cognitive functioning can be maintained in the older population is becoming increasingly emphasized.

Second, substantial evidence suggests that older adults do not perform as well as younger adults on a variety of cognitive tasks (Botwinick, 1977; Cunningham, 1987; Jacewicz & Hartley, 1987; Schaie, 1990). Other evidence shows that older adults perform less well than younger adults on psychomotor tasks (Cerella, 1990; Salthouse, 1985; Stelmach & Nahom, 1992). However, while it is fairly well established that older adults experience cognitive decrements which hinder their ability to perform certain tasks, very little research has been conducted to examine the relationship between aging and the ability to learn new motor skills (Anshel, 1989; Williams, 1989).

A relatively permanent change in the capability to respond, or learning, is ascertained by having a person perform either the same task or a variation of the task at a subsequent testing session (retention period) and then showing that the performance is better than during the initial acquisition trial (Schmidt, 1988). Using this definition, only one study has been conducted that actually assessed motor task learning as a function of age. Carnahan, Vandervoort, and Swanson (1993) reported on a series of three experiments designed to determine whether factors associated with motor learning operate differently in younger and older adults. The experiments were designed to examine the relationships between age and learning with regard to contextual interference, extrinsic knowledge of results, and the provision of summary results. The results showed that in all three experiments, older adults performed less well than younger adults across acquisition blocks. In two of the three experiments, older adults showed worse performance at retention than did younger adults, and in the third experiment there were no differences in retention performance as a function of age. None of the studies evidenced an interaction effect between the treatment variable and age. For example, the use of a blocked versus random practice schedule did not impact performance differentially based on age. Thus, the overall conclusion drawn by the authors was that older participants did not perform as well at acquisition or retention as younger participants, but the influence of manipulated variables related to the learning paradigm did not differ as a function of age. In addition to replicating previous results with a sample of younger adults (Etnier et al., 1996), the present study was also designed to extend the past research by examining the influence of age on motor learning capabilities. It was hypothesized that younger participants would perform better and show greater learning than older participants.

A second independent variable which was included to extend the prior research was aerobic fitness. Results from a meta-analysis on cognitive functioning and physical fitness (Etnier et al., 1997) have shown that fitness has a moderate effect on cognitive ability (ES = .25). This may be an especially important consideration in examining the relationship between age and cognition, because the evidence from cross-sectional studies has consistently shown that, among older participants, fitness moderates cognitive ability (Diesfeldt & Diesfeldt-Groenendijk, 1977; Elsayed, Ismail, & Young, 1980; Spirduso, 1975). However, while one study has examined the influence of age on motor learning capabilities (Carnahan et al., 1993), no study has examined the relationship between fitness and age in relation to motor learning. Based on past results with cognitive performance, it was hypothesized that older participants with higher fitness levels would perform better and demonstrate greater learning than older participants with lower fitness levels.

Method

Participants

Younger (ages 20-30 years, n = 42) and older (ages 60-80 years, n = 41) right-handed male participants were recruited from a southwestern university and the surrounding community. Students received extra credit points in exercise science classes for their participation. Older participants received compensation for their parking expenses. Younger participants were tested during an 8-month period beginning in February, and older participants were tested during a 12-month period beginning in March of the same year. The difference in the time frame for testing occurred because it was more difficult and, therefore, more time consuming to recruit older participants. All participants read and signed an informed consent form and completed a standard health history questionnaire which was examined to ensure that participants were free of coronary artery disease and physical impairments.

Experimental Design

Participants were randomly assigned to either the control group or experimental group. Performance and EEG data were assessed at a pretest and a posttest on the acquisition day and again during Trials 1-10 and 11-20 on the retention day. The performance variables were: distance (operationalized as the number of segments traversed on the star) and errors (operationalized as the total errors per 8-s trial divided by distance). A 2 x 2 x 2 x 2 x 2 repeated measures design was used for the performance data, with Treatment Group (experimental, control), Age Group (young, older), and Fitness Group (unfit, fit) as between-subjects variables and Trial Block (pretest or 1-10, posttest or 11-20) and Day (acquisition, retention) as within-subjects variables. EEG alpha was analyzed in a 2 x 2 x 2 x 2 x 2 x 4 x 2 design. Treatment Group, Age Group, Fitness Group, Day, and Trial Block were the same as described previously, and two additional within-subjects variables were Site (frontal, temporal, central, parietal) and Hemisphere (left, right).

Performance

As in the Etnier et al. (1996) study, motor performance was measured using a Lafayette Instrument Automatic Mirror Trace (Model 5824, Lafayette Instrument Company, Lafayette, IN). Participants held a metal stylus in their right hands to trace the outline of a 6-point star. The task is considered novel, because participants were required to trace the star using a mirrored view of the star and their hand as their only visual stimulus. Direct viewing of the star itself was not possible, because a metal screen was set above the star and the performer's hand to completely block direct observation of the star and the hand. An adjustable mirror was positioned at the back of the star and angled to provide an indirect view of both the star and the performer's hand.

Performance was scored as distance traveled around the star and the number of errors made relative to distance in each 8-s trial. Along the edge of the star, lines marked off quarters of the distance between adjacent corners. Distance was scored as the total number of segments traversed accurate to one-quarter of a segment. The reliability coefficients for each block of 10 trials were computed and found to range from .94 to .97. The star itself was painted in nonmetallic black on a metal surface and was set up so that any time the metal surface was touched with the stylus, an electronic counter automatically scored an error.

EEG Assessment

An E1 Electro Cap (Electro-Cap International, Eaton, OH) was put on the participants' heads and positioned so that the distance from the front edge of the cap to the bridge of the nose was one-tenth the total distance from the protrusion at the base of the scalp to the bridge of the nose. To ensure proper relative electrode placement, the electrode caps come in four sizes (46-50, 50-54, 54-58, and 58-62 cm) (Blom & Anneveldt, 1982). The caps are made of elastic spandex-type fabric and have recessed, pure tin electrodes sewn in. Electrode gel was applied to the relevant electrodes to create the conductivity needed for taking scalp measures of EEG activity. EEG recordings were taken from the following eight sites identified by the International 10-20 System (Jasper, 1958): left frontal (F3), right frontal (F4), left central (C3), right central (C4), left temporal (T3), right temporal (T4), left parietal (P3), and right parietal (P4). Electrical impedance was measured at 30 Hz, and electrode gel was reapplied to any sites which had impedances greater than 5 K ohms.

Electrodes were placed at the supra-orbit and external canthus of the right eye to record eye blinks. Additionally, an electrode on the nose was used as a reference electrode. The sites surrounding the eye and nose were lightly abraded and cleaned with isopropyl alcohol. After cleaning the sites, Beckman 11-mm Ag-AgCl electrodes were applied (Beckman Coulter, Inc., Fullerton, CA). Electrical impedance was measured at 30 Hz, and electrodes were reapplied to any site which had impedances greater than 10 K ohms.

The psychophysiological measures were collected using a Grass Model 12 Neurodata Acquisition System (Grass Instruments, West Warwick, RI) physiograph and software developed by Neuroscan, Inc. (Sterling, VA). The high and low bandpass filters for the EEG signals were set at 0.1 Hz and 100 Hz, respectively, and the amplifiers were set at 50,000 times. The high and low bandpass filters for the electro-oculographic (EOG) signals were set at 3 Hz and 100 Hz, respectively, and the amplifiers were set at 20,000 times. The attenuation of the EEG signal with these filter settings was less than 5% from 0.5 Hz to 20 Hz. The sampling rate for all signals was 256 Hz. The fast Fourier transform to determine spectral power was done using software developed at Arizona State University (Waterman, 1994).

Fitness Assessment

In the younger participants, a graded exercise protocol was used with a bicycle ergometer to assess maximal oxygen consumption (VO_2max) (Åstrand & Rodahl, 1977) . A bicycle ergometer was used instead of a treadmill because of safety concerns with regard to the balance capabilities of the older participants. Participants were equipped with a noseclip and a mouthpiece. The VO_2 data were provided by a Vista On-Line system (Sensormedics, Yorba Linda, CA), and the gases were analyzed with a Beckman Oxygen Analyzer OM-11 and a Beckman Medical Gas Analyzer LB-2 (Beckman Coulter, Inc., Fullerton, CA). Participants pedaled at a comfortable, steady pace between 60-80 rpms. The initial workload was 100 W, which participants maintained for 3 min. Following this, workload was increased by 50 W every 2 min until volitional exhaustion.

In older participants, a submaximal bicycle test was used to estimate VO_2max (Åstrand & Rodahl, 1977). A submaximal test was used instead of a maximal test because of the risks involved in conducting a maximal test with this age group. Participants pedaled at a comfortable, pace between 60-80 rpms. Participants started pedaling at a workload of either 10 or 20 W, based on their self-reported physical activity level (10 W for low activity, 20 W for normal or high activity), and this was increased by the same amount every 3 min. The protocol was flexible, because at least nine heart rate measures (equivalent to 9 min of activity) were desired for estimating VO_2max. Heart rate was measured near the end (last 10 s) of each minute, and blood pressure was assessed in the last minute at each level. In accordance with the Exercise and Sport Research Institute policies, each participant performed the submaximal test only as long as the heart rate remained below 75% of the age-predicted maximal heart rate (220-Age). Predicted VO_2max was determined by calculating the equation for the line between the last three heart rate responses and then determining what the maximal work load would be, given the maximal predicted heart rate (American College of Sports Medicine, 1991).

Physical Activity Level

Because researchers have suggested that VO_2max may reflect genetic factors more than actual activity levels (Bouchard & Lortie, 1984; Bouchard & Malina, 1983), activity questionnaires were also given to participants. The Questionnaire for the Measurement of Habitual Physical Activity (Baecke, Burema, & Frijters, 1982) was given to younger participants, and a modification of this questionnaire (Voorrips, Ravelli, Dongelmans, Deurenberg, & Van Staveren, 1991) was given to the older participants. The questionnaire had been modified from that given to younger adults so that the questions were more geared toward the activities of older adults. However, both questionnaires were scored in similar manners, and both assessed activity levels in three different areas.

Procedure

Participants came to the laboratory on three different occasions. On the first day, they read and signed the informed consent, completed a health history questionnaire and the physical activity questionnaire, answered a series of questions relative to their current physical activity level and contraindications for exercise (British Columbia Department of Health, 1975), and then had three electrodes applied to record electrocardiographic activity. Participants then performed the aerobic fitness test (maximal VO_2 test for younger, submaximal test for older). Following this, participants were randomly assigned to either the control group or the experimental group. Randomization was performed using a coin toss with the restriction that half the participants from each age group were assigned to the experimental group and the other half to the control group.

The acquisition day occurred at least 24 hr after the first day. On the acquisition day, EEG and EOG electrodes were applied, and participants were instructed on the task to be performed. Participants were told to perform multiple 8-s trials and asked to try to go as far as possible on the star with as few errors as possible. The participants then listened to the series of three tones which would serve as their signals for the trials. These tones consisted of a warning signal (low tone), followed at a variable period (.5 s, 1 s, 1.5 s) by a "Go" signal (medium tone), followed 8 s later by a "Stop" signal (high tone). When they heard the stop signal, participants were asked to immediately stop moving the stylus so that their performance for that trial could be scored. The intertrial interval was 8 s.

On the acquisition day, participants in the experimental group performed 175 trials with 3-min breaks after each group of 60 trials. These trial blocks were approximately 16 min long; participants actually performed the task for half of this period and rested for the other half. The control group of participants performed 10 trials and then sat quietly and read *The Reader's Digest* for 41 min. This is equivalent to the amount of time needed to perform 155 trials. These participants then performed 10 more trials. After breaks from performing, all participants were verbally reminded of the instructions: "go as far as possible with as few errors as possible."

All participants returned to the lab 24-72 hr after acquisition for retention tests. On this day, participants' setup and instructions were identical to those on the acquisition day. Additionally, the time of day at which the testing was conducted was approximately the same as on the acquisition day (within 2 hr). All participants performed 20 trials of the mirror star trace on this day.

Data Reduction

Distance data, error data, and EEG data were averaged within each block of 10 trials and analyzed for the pretest (Trials 1-10) and posttest (Trials 166-175 for the experimental group, Trials 11-20 for the control group) on the acquisition day and for Trials 1-10 and Trials 11-20 on the retention day.

Before further analyses were conducted, three participants were omitted from the sample due to missing data. One older experimental participant was excluded because he was taking medication that influenced his heart rate and affected the accuracy of the VO_2max measure. One younger experimental participant and one younger control participant were excluded because their EEG data were contaminated with movement artifact. Thus, the remaining number of participants in each level of Age Group by Treatment Group was 20.

EEG activity was measured continuously for the first 10 trials on the acquisition day (pretest), for the last 10 trials on the acquisition day (posttest), and for 20 trials on the retention day. Prior to conducting the fast-Fourier transform analysis, EEG files were visually examined so that portions of the data which were contaminated by artifact could be marked for exclusion. The stimulus computer which produced the warning, go, and stop signals for the motor task also produced standard 5-volt pulses in the EEG acquisition computer; these pulses were accurate to the interrupt handling latency of the software package (1 ms). The spectral data were analyzed between the presentation of the go signal and the presentation of the stop signal.

Data Analysis

Initially, analysis of variance was used to verify that the groups were not different on variables which could potentially moderate the effects (e.g., education, physical activity level). The distance and error data were analyzed using a repeated measures doubly multivariate analysis of variance (MANOVA). The dependent variables were examined at acquisition pretest, acquisition posttest, Retention Trials 1-10, and Retention Trials 11-20. Thus, Trial Block and Day were repeated measures variables. Age Group, Treatment Group, and Fitness Group were categorical, independent variables. Fitness Group was determined by a median split within each age group and classifying those above the median as fit and those below it as unfit (younger: median = 41.11 ml/kg/min; older: median = 26.01 ml/kg/min). Because this median split could only be done after all participants had been tested and therefore followed the random assignment to treatment groups, unequal cell sizes resulted in the older groups as follows: older fit experimental (n = 11), older unfit experimental (n = 9), older fit control (n = 9), older unfit control (n = 11). The distance data across all acquisition trials was also analyzed for the experimental group, with a MANOVA method for repeated measures analysis with Age Group and Fitness Group as between-subjects factors and Trial Block (Trial Blocks 1-17) as the repeated measures factor. This was done to examine performance acquisition differences as a function of Age and Fitness Groups.

The EEG data were analyzed using a MANOVA method for repeated measures analysis, with Treatment Group, Age Group, and Fitness Group as the between-subjects factors and Day, Trial Block, Site, and Hemi sphere as within-subjects factors.[1] The dependent variable was alpha power at each of the trials (pretest acquisition, posttest acquisition, Retention Trials 1-10, Retention Trials 11-20).[2]

When necessary, the Huynh-Feldt epsilon was examined to check the sphericity assumption. In cases in which the assumption was not met (i.e., $\varepsilon < .75$), multivariate tests of significance were used. To further examine the highest order interactions which reached significance and were of theoretical interest, simple effects were examined using pairwise comparisons. In these examinations, alpha levels were divided by the number of pairwise comparisons made. In recognition of the low power of these follow-up tests, cell means were presented for those significant interactions predicted based on the past literature. For all significant effects, ε^2 values were reported as an index of meaningfulness.

Results

Initial Differences

Demographic data are presented in Table 1 as a function of Age Group, Fitness Group, and Treatment Group. Results showed no significant difference in years of education since high school as a function of Age Group, Fitness Group, or Treatment Group *($p > .05$).* There was a significant main effect for Fitness Group on weight, $F(1, 79) = 11.03$, $p < .001$, such that fit participants ($M = 76.03$ kg, $SD = 9.12$) weighed significantly less than unfit participants ($M = 83.86$ kg, $SD = 11.80$). There was also a significant main effect for Age Group on self-reported physical activity level, $F(1, 79) = 13.91$, $p < .001$, such that the scores for the older participants ($M = 11.63$, $SD = 7.51$) were significantly higher than those for the younger ones (M = 7.09, $SD = 1.32$).[3] For VO_2max, there was a significant main effect for Age Group, $F(1, 79) = 146.14$, $p < .001$, such that younger participants ($M = 43.05$ ml/kg/min, $SD = 9.15$) were significantly more fit than older participants ($M = 28.30$ ml/kg/min, $SD = 9.82$). Examination of the time interval between acquisition and retention trials indicated that there was not a significant difference as a function of Age Group, Fitness Group, Treatment Group, or the interactions of these variables, $F(1, 75) = 0.00\text{-}2.65$, $p > .05$. Importantly, for the older participants, there was no significant

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[1] An examination of standard deviations for the EEG data by Age Group, Treatment Group, and Fitness Group showed that in some cases the standard deviations were quite disparate so that the assumption of homogeneity of variance was violated. Because this can result in an inflated alpha level, a natural logarithmic transformation of the data was conducted, which resulted in homogeneous variances. The results from a MANOVA using the transformed alpha scores as the dependent variables showed that the all the effects which had reached significance using the raw scores were still significant. Therefore, it was decided that the unequal variances did not have a meaningful impact on the results, and, to ease the interpretation of the results, all reported analyses are from the raw scores.
[2] Beta power was also examined, but the effects found to be significant were not relevant to the hypotheses of interest. Therefore, the results are not presented in the text. However, the results are available from the author on request.
[3] In interpreting this result, remember that younger participants completed the Baecke et al. (1982) questionnaire, while older participants completed the Voorrips et al. (1991) questionnaire. Examination of the questionnaires' scoring systems showed that the age-related difference in the scores was due to differences in scoring systems rather than participants' activity levels.

difference in years since retirement as a function of Fitness Group, Treatment Group, or their interaction ($p > .05$).

To address the question of whether differences in VO_2max actually reflect differences in activity level, the activity levels of each fitness group were examined within each age group. Examination of the self-reported physical activity levels within each Age Group showed that participants classified as fit (younger: $M = 7.55$, $SD = 1.34$; older: $M = 13.01$, $SD = 7.94$) reported more physical activity than did participants classified as unfit (younger: $M = 6.63$, $SD = 1.15$; older: $M = 10.26$, $SD = 6.98$).

Performance Data

Means and standard deviations are presented in Table 2. The multivariate test indicated that the highest order interactions to reach significance were the Age Group x Day x Trial Block interaction, Wilks' $\Lambda = .82$, $F(2, 71) = 7.94$, $p = .001$, 102 = .18, the Treatment Group x Day x Trial Block interaction, Wilks' $\Lambda = .34$, $F(2, 71) = 69.84$, $p < .001$, $\varepsilon^2 = .66$, and the Treatment Group x Fitness Group x Day interaction, Wilks' $\Lambda = .88$, $F(2, 71) = 4.74$, $p < .001$, $\varepsilon^2 = .12$. Examination of the univariate F tests for the Age Group x Day x Trial Block interaction revealed this interaction was significant for both distance, $F(1, 72) = 5.06$, $p < .03$, $\varepsilon^2 = .07$, and errors, $F(1, 71) = 12.41$, $p < .001$, $\varepsilon^2 = .15$. Examination of the univariate F tests for the Treatment Group x Day x Trial Block interaction showed the interaction was only significant for distance, $F(1, 72) = 137.70$, $p < .001$, $\varepsilon^2 = .66$. Examination of the univariate F tests showed that the Treatment Group x Fitness Group x Day interaction was only significant for errors, $F(1, 72) = 7.82$, $p < .01$, $\varepsilon^2 = .10$.

Distance. Simple main effects conducted for the Age Group x Day x Trial Block interaction indicated that participants improved their performance significantly from pretest acquisition ($M = 3.22$, $SD = 1.71$) to posttest acquisition ($M = 8.31$, $SD = 4.70$), $t(79) = 10.876$, $p < .001$; they did not change significantly from posttest acquisition to Retention Trials 1-10 ($M = 8.23$, $SD = 4.02$), $t(79) = 0.37$, $p > .05$; and they improved significantly from Retention Trials 1-10 to Retention Trials 11-20 ($M = 9.88$, $SD = 4.77$), $t(79) = 10.21$, $p < .001$. Additionally, the younger participants performed significantly better than older participants at every trial block, $t(78) = 3.04\text{-}6.80$, $p < .001$, and the difference in mean performance became greater across trial blocks (see Figure 1a).

Simple main effects for the Treatment Group x Day x Trial Block interaction revealed that the pretest acquisition performance of the treatment groups was not significantly different, $t(78) = 0.36$, $p > .05$, but at posttest acquisition, $t(78) = 8.49$, $p < .001$, at Retention Trials 1-10, $t(78) = 5.54$, $p < .001$, and at Retention Trials 11-20, $t(78) = 5.96$, $p < .001$, participants in the experimental group performed significantly better than control participants (see Figure 1b).

Errors. Simple main effects conducted for the Age Group x Day x Trial Block interaction revealed that the older participants made significantly more errors per distance traveled than the younger participants at all trial blocks, $t(79) = 3.99\text{-}5.21$, $p < .001$; however the mean difference was greatest at the acquisition pretest and less at the other trial blocks (see Figure 2).

Table 1. Demographic variables as a function of age group by fitness group by treatment group

	YUE		OUE		YUC		OUC		YFE		OFE		YFC		OFC		E		C	
	M	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***
Education (years beyond HS)	5.00	1.33	5.56	3.57	3.25	1.03	4.00	2.32	4.55	2.19	6.00	4.65	5.45	1.67	6.56	4.45	5.29	3.16	4.75	2.82
Age (years)	25.10	2.47	68.11	5.75	22.90	1.91	69.64	5.26	23.30	2.63	66.91	4.91	24.00	2.91	64.89	5.58	45.83	22.28	45.58	22.74
Weight (kg)	83.41	10.58	84.37	11.52	87.39	11.86	80.66	13.61	72.09	6.05	77.93	8.58	78.43	10.33	75.43	10.96	79.29	10.22	80.61	12.18
VO_2max (ml/kg/min)	36.15	2.24	19.74	4.48	35.25	3.50	20.89	3.14	53.61	8.14	36.04	7.85	47.18	3.98	36.40	6.82	36.79	13.27	34.54	10.63
Physical activity level	5.99	1.01	8.60	7.85	7.28	0.92	11.63	6.23	7.79	1.41	12.04	7.32	7.31	1.29	14.18	8.94	8.69	5.69	10.03	5.95
Years since retirement			9.67	8.89			7.41	9.04			5.14	4.35			3.00	5.09	7.18	6.97	5.43	7.68

Note. Y = younger; D = older; F = fit; U = unfit; E = experimental; C = control; HS = high school.

Table 2. Performance and errors as a function of age group, fitness group, and treatment group

	YUE		OUE		YUC		OUC		YFE		OFE		YFC		OFC	
	M	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***
Pretest acq perf (segments)	4.90	1.16	1.78	0.66	3.48	1.06	1.83	1.38	3.75	1.30	2.15	1.43	4.92	1.65	3.08	1.28
Posttest acq perf (segments)	13.54	3.28	8.84	3.46	5.50	1.53	3.14	2.42	13.15	2.81	10.51	5.18	7.15	1.84	4.68	2.02
Pretest ret perf (segments)	12.58	2.90	7.36	3.01	6.72	1.50	4.08	2.94	13.00	3.12	8.36	3.82	8.53	1.51	5.20	2.48
Posttest ret perf (segments)	14.85	2.97	9.28	3.74	7.97	1.30	5.28	3.94	14.77	3.65	11.05	5.78	9.67	1.21	6.11	2.83
Pre acq abs errors (errors)	2.78	2.16	2.95	1.39	3.06	1.42	3.98	3.11	2.05	1.09	3.76	2.49	2.46	1.33	3.68	2.47
Post acq abs errors (errors)	4.93	2.75	5.18	3.31	2.77	1.58	4.25	4.56	4.78	1.62	7.08	4.90	3.04	1.31	4.29	3.92
Pre ret abs errors (errors)	4.00	2.20	4.96	2.72	3.40	1.62	4.90	4.65	4.17	2.22	5.43	4.27	3.42	1.76	4.84	3.58
Post ret abs errors (errors)	4.54	2.16	5.72	4.27	4.00	2.08	5.08	5.15	4.47	2.68	7.19	6.12	4.15	1.53	5.44	3.27
Pre acq stand errors (errors/segments)	0.60	0.56	2.00	1.58	1.02	0.71	3.16	2.53	0.63	0.47	2.01	1.14	0.52	0.30	1.19	0.82
Post acq stand errors (errors/segments)	0.36	0.17	0.58	0.21	0.50	0.23	1.41	1.13	0.38	0.18	0.67	0.31	0.43	0.15	0.84	0.53
Pre ret stand errors (errors/segments)	0.32	0.18	0.71	0.26	0.52	0.26	1.18	0.62	0.32	0.17	0.62	0.36	0.39	0.17	1.01	0.75
Post ret stand errors (errors/segments)	0.31	0.15	0.61	0.29	0.51	0.27	0.87	0.48	0.31	0.19	0.59	0.34	0.43	0.14	0.91	0.42

Note. Y = younger; O = older; F = fit; U = unfit; E = experimental; C = control; acq perf = acquisition performance; ret perf = retention performance; acq abs = acquisition absolute; ret abs= retention absolute; acq stand = acquisition standardized; ret stand = retention standardized.

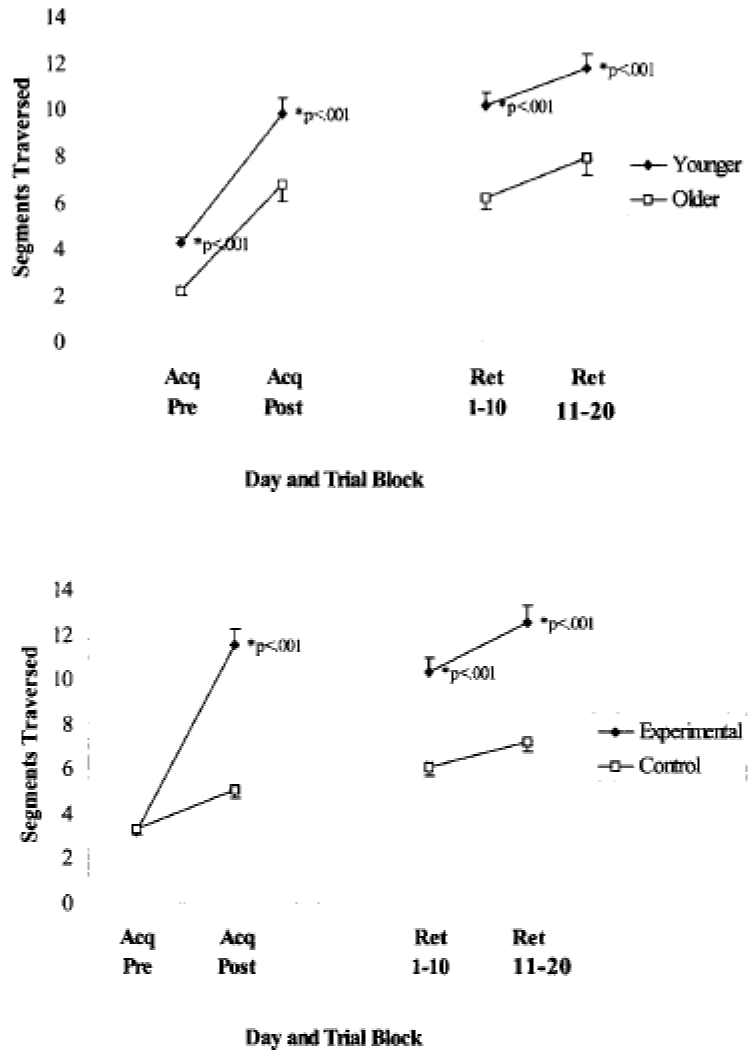

Figure 1. Mirror star trace performance (segments traversed) (a) as a function of Age Group x Day x Trial Block and (b) as a function of Treatment Group x Day x Trial Block.

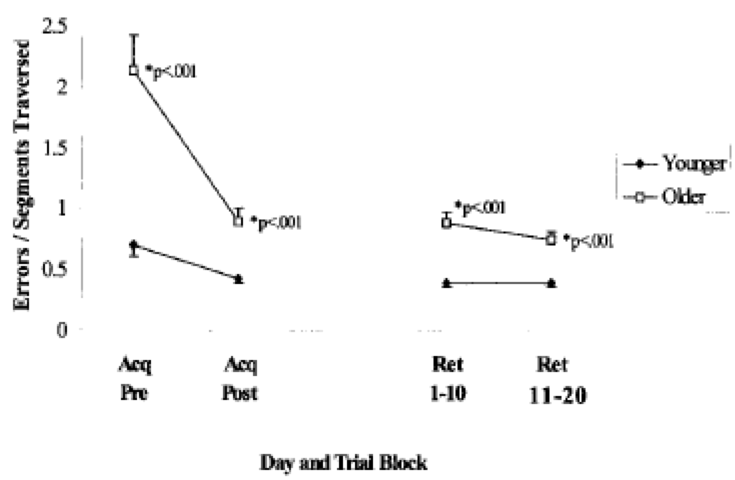

Figure 2. Errors (errors/segments traversed) as a function of Age x Day x Trial Block.

Simple main effects for the Treatment Group x Fitness Group x Day interaction were examined. For all groups, errors decreased significantly from acquisition to retention, $t(79) = 4.20$, $p < .001$. Additionally, examination of the interactions involving the between-groups factor indicated that the control participants ($M = 0.72$, $SD = 0.47$) made significantly more errors, $t(78) = 2.87$, $p < .01$, than did the experimental participants ($M = 0.47$, $SD = 0.29$) across the retention trials. The three-way interaction obtained significance, because at acquisition the unfit control group ($M = 1.56$, $SD = 1.41$) made significantly more errors, $t(38) = 2.41$, $p < .05$, than did the fit control group ($M = 0.73$, $SD = 0.54$); while at retention, none of the groups was significantly different from each other.

Effects of Repeated Practice

The findings for the mirror star trace were further examined by analyzing average performance across Trial Blocks 1-17 for the experimental participants only. Results showed that there was a main effect for Age Group, $F(1, 36) = 19.27$, $p <.001$, $\varepsilon^2 = .35$, such that younger participants performed better than older participants. There was also a main effect for Trial Block, Wilks' $\Lambda = .06$, $F(16, 21) = 19.97$, $p < .001$, $\varepsilon^2 = .94$, such that participants improved across trials. The fact that none of the interactions involving Trial Block reached significance suggests that there were no differences in the acquisition of performance proficiency as a function of either Age Group, Fitness Group, or their interaction.

Alpha Power

There were significant main effects for Site, Wilks' $\Lambda = .38$, $F(3, 67) = 36.75$, $p < .001$, $\varepsilon^2 = .62$, Hemisphere, $F(1, 69) = 9.70$, $p < .01$, $\varepsilon^2 = .12$, and Trial Block, $F(1, 69) = 16.46$, $p < .001$, $\varepsilon^2 = .19$. These main effects were all superseded by significant two-way interactions involving them. There was a significant Site x Hemisphere interaction, $F(3, 67) = 13.15$, $p < .001$, $\varepsilon^2 = .37$, a significant Site x Trial Block interaction, Wilks' $\Lambda = .71$, $F(3, 67) = 9.20$, $p < .001$, $\varepsilon^2 = .29$, a significant Day x Trial Block interaction, $F(1, 69) = 13.56$, $p < .001$, $\varepsilon^2 = .16$, and a significant Fitness Group x Site interaction, Wilks' $\Lambda = .88$, $F(3, 67) = 3.09$, $p < .05$, $\varepsilon^2 = .12$. All of these effects were also superseded by higher order interactions.

There was a significant Fitness Group x Site x Hemisphere interaction, Wilks' $\Lambda = .86$, $F(3, 67) = 3.60$, $p < .02$, $\varepsilon^2 = .14$. None of the follow-up *t* tests yielded significant effects. However, examination of the means indicated that the fit group had higher alpha activity at every site in both hemispheres (except T4).

There was a significant Treatment Group x Site x Day interaction, $F(3, 67) = 3.29$, $p < .03$, $\varepsilon^2 = .13$. Follow-up *t* tests did not yield significant results. However, examination of the means from acquisition to retention within the Treatment Groups indicated that both groups had decreases in frontal and parietal alpha; but that the experimental group had an increase in central alpha while the control group had a decrease in central alpha and the experimental group had a decrease in temporal alpha while the control group showed an increase in temporal alpha.

There was also a significant interaction for Site x Day x Trial Block, $F(3, 67) = 4.97, p < .01, \varepsilon^2 = .18$. Dependent samples *t* tests indicated that alpha activity increased significantly, $t(77) = 2.89\text{-}3.39, p < .005$, from acquisition pretest to acquisition posttest at all sites. At all sites, alpha activity during Retention Trials 1-10 was less than at acquisition posttest but more than at the acquisition pretest (see Figure 3).

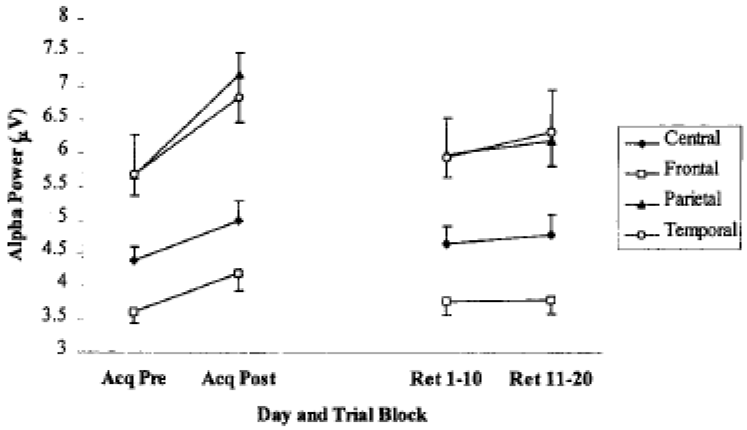

Figure 3. Alpha power as a function of Site x Day x Trial Block.

There was a significant interaction effect of Age Group x Fit Group x Hemisphere x Trial Block, $F(1, 69) = 4.79, p < .05, \varepsilon^2 = .07$. Follow-up tests indicated that alpha activity increased significantly, $t(76) = 3.91\text{-}4.06, p < .001$, from pretest to posttest in both hemispheres. There was also a significant interaction of Age Group x Day x Trial Block x Hemisphere x Site, Wilks' $\Lambda = .88$, $F(3, 67) = 2.92, p < .05, \varepsilon^2 = .12$. Examination of this effect indicated that younger participants had greater alpha activity at all sites and trial blocks but that this effect was only significant at T4 during the acquisition pretest, $t(77) = 2.42, p < .02$.

Discussion

In terms of performance capabilities, the results indicate that advancing age had a significantly negative impact on performance. This was evidenced by the fact that younger participants traversed a greater distance and had fewer relative errors than older participants at the pretest. This supports the hypothesis and the findings of past research which suggest that older adults do not perform as well on cognitive or motor tasks as do younger adults.

With regard to the influence of fitness on performance, the hypothesis was not supported. That is, fitness did not have a significant impact on the distance traversed on the task and had only an inconsistent impact on the error data. Therefore, the results of this study indicate that fitness does not influence motor performance capabilities. However, it is important to qualify this statement to some extent. The impact of fitness on performance was only expected to exist for the older adults, and while there was not a significant interaction for Age Group x Fitness Group on the distance data, an examination of the effect size for the older participants as a function of fitness indicates that meaningful differences may exist. The effect size was 0.60, which suggests that given the same effects as those found in the present study, 1a sample of 70 adults between the ages of 60-80 years would yield significant fitness differences in initial performance. Additional support for the existence of this relationship is provided by examining the relative performance scores. At the pretest, the older unfit participants performed at 43% relative to the younger unfit participants, while the older fit participants performed at 59% relative to the younger fit participants. Finally, the fitness measures for older individuals were somewhat limited, because, for safety reasons, the older participants only completed submaximal measures of VO_2. Therefore, it is possible that the fitness effect was blunted due to the need to test the older individuals more conservatively. Taken together then, it remains possible that fitness may moderate performance in older adults, and research should continue to address this issue.

The results with regard to learning as a function of age are somewhat difficult to interpret. That participants in the experimental group performed better than the control group at retention provides evidence that substantial practice on this task led to a permanent change in the capability to perform. This supports the findings of past research using this same task (Etnier et al., 1996) and provides evidence that learning actually occurred on this task. However, the interactions of Treatment Group x Age Group x Trial Block and of Treatment Group x Age Group x Fitness Group x Trial Block were not significant. This means that the additional practice the experimental group received did not lead to differential improvement as a function of age or fitness level. This supports the findings of Carnahan et al. (1993) who concluded that the effect of variables found to be related to learning did not differ as a function of age. This conclusion is further supported by examining the influence of repeated practice on performance in the experimental group. The results showed that younger participants were consistently better than older participants, but that the rate of improvement across trials during the acquisition period did not differ as a function of the Age Group x Fitness Group interaction.

The complication in interpreting these learning results arises from the fact that there were significant Age Group x Trial Block interactions for both distance and errors. The distance data showed that younger participants performed increasingly better than older participants across trials. This suggests that with repeated testing, younger participants improved more than older participants regardless of whether they received substantial practice (experimental group) or minimal practice (control group). However, there was also a significant Age Group x Trial Block interaction for the error data. This testing effect showed that across trial blocks, the number of errors made relative to distance decreased for all participants; however, older participants showed a greater decrease in errors than younger participants. However, two things with regard to this finding are important. First, a "floor effect" may have occurred such that the younger participants performed with such accuracy that it was difficult to demonstrate further improvement. Second, the older adults never surpassed the younger adults in accuracy of performance, and at retention the younger participants' performance was more accurate than the older participants. Thus, it is concluded that younger participants were always better than older participants in both distance traversed and the number of errors made. Additionally, it is concluded that younger participants show greater learning capabilities than older participants in distance traversed. Because the accuracy of younger participants' performance was always higher than older participants, it is concluded that the findings with regard to learning are not refuted by the error data.

The EEG results provide some support for earlier research (Etnier et al., 1996). The results of the present study revealed significant interactions for Treatment Group x Site x Day and for Site x

Day x Trial Block. That these interactions were significant indicates that changes in EEG activity do occur with learning and differ as a function of the amount of practice provided on the task. The changes in EEG activity from trial block to trial block (see Figure 3) nearly exactly replicate those found in the previous study (Etnier et al., 1996). However, the interpretation of the Treatment Group interaction found in this study is different from that resulting from the previous study. In the Etnier et al. (1996) study, the Treatment Group x Hemisphere x Day x Trial Block interaction was significant and indicated that the experimental group had a greater increase in right hemisphere alpha from acquisition pretest to acquisition posttest than the control group. The results from this study showed that the treatment groups had different changes in alpha as a function of the cerebral sites. These results appear to be conflicting and to leave this discussion at this point would be misleading. However, if we examine the means from this study, which would be involved in the Treatment Group x Hemisphere x Day x Trial Block interaction, this can greatly clarify the results. While this interaction was not significant and, therefore, may not be reliable, the means indicate that in both hemispheres both groups showed increases in alpha from pretest acquisition to posttest acquisition and this increase in alpha activity was larger for the experimental group than for the control group. Then, from the posttest acquisition to Retention Trials 11-20, alpha activity decreased in both hemispheres, but it remained higher than it had been at the acquisition pretest.

Thus, in two separate studies using different samples and participants of different age ranges, it was found that increases in spectral alpha were reliably associated with improved performance capabilities on a motor task, and these increases were larger (reliably so in Etnier et al., 1996) for the group which received the most practice on the motor task. Similar results from past studies have been interpreted to suggest that increased alpha power is synonymous with increased synchronicity of neural firing, and this is equivalent to an increase in brain efficiency (Haier et al., 1992). The implication, then, is that participants who achieve this efficiency are able to achieve an increase in their behavioral efficiency, which is manifested as improved performance. However, the cause-and-effect nature of this relationship cannot be clearly defined. It is possible that increases in alpha activity reflect an improved efficiency of brain functioning, which allows the performer to show sustained improvement on the task. However, an equally viable explanation is that the participants become more relaxed in response to their improved performance, which is the reason for increases in alpha power.

Prior to summarizing the results of this study, there are a number of important points which should be iterated. First, it is important to note that the participants in this study classified as "fit" based on VO_2max measures also had higher levels of physical activity than the "unfit" participants. Thus, the conclusions of this study hold, despite concerns that measures of VO_2max may not reflect actual activity levels (Bouchard & Lortie, 1984; Bouchard & Malina, 1983; Boutcher, 1993). Second, the findings with regard to the error data are important because of the suggestion that differences in performance capabilities as a function of age may actually just represent age-related differences in the emphasis on speed versus accuracy (Ford & Pfefferbaum, 1985). That is, it has been suggested that older participants do not perform as well on speeded tasks, because they focus more on accuracy than the speed of their response. However, the error data refute this contention. Younger participants actually made fewer errors relative to the distance they covered than did older participants so that the aforementioned performance differences were not a result of differing interpretations of the task demands. Third, the results of this study basically replicate those of a previous study (Etnier et al., 1996) which used the same task in a different sample of participants and found similar increases in alpha activity associated with improvements in performance.

Thus, the results of the present study suggest that there are age-related decrements in motor performance and motor learning capabilities. Additionally, the results indicate that fitness does not impact performance or learning capabilities on this task. Finally, the results show changes in the EEG spectral alpha which occur in conjunction with learning and do not differ as a function of age or fitness but as a function of the amount of practice on the task.

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